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HRSC DIGITAL TERRAIN MODEL AND TERRAIN-CORRECTED IMAGES OF THE SOUTH POLE OF MARS

Prepared by UCL Team
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APPROVAL

CHANGE LOG

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1. INTRODUCTION

Within the EU FP-7 iMars project (http://www.i-mars.eu), it was realised that a complete Martian South-Polar Digital Terrain Model would be helpful for Martian polar research. An enhanced processing system (Kim and Muller, 2009) based on the NASA-VICAR-based pipeline developed by JPL (Jet Propulsion Laboratory) with modifications from DLR (German Aerospace Centre) was employed for this purpose. The main modification from UCL was replacing the image matcher with the Gotcha (Gruen-Otto-Chau) algorithm (Shin and Muller, 2012) and applying this to a specialised setup for the polar region using 64-bit processing.

HRSC orbital strip DTM products were produced on an areoid (gravity) reference surface with a resolution of 50 m/pixel in the same co-ordinate system as the gridded Mars Orbiter Laser Altimeter (MOLA) of 512 pixels/degree (112 m/pixel) over the South Polar Residual ice Cap (SPRC). MOLA includes a gap over the Mars South Polar region (82° - 90° S) whereas the HRSC products cover this gap. These orbital strip-based products were then mosaiced into a 50m/pixel DTM and a 12.5m/pixel OrthoRectified Image (ORI) of the panchromatic channel. See (Putri et al., 2019) for further details.

The accuracy of the HRSC orbital 50m DTMs were assessed against the MOLA reference with good results (loc.cit.). These validated products are being made open-source to the planetary science community through a collaboration with ESA PSA. In addition, browse products have been produced using colour-height hill-shading and these browse products are visualisable through the iMars WebGIS system (http://www.i-mars.eu/webgis). The individual orbital HRSC DTM & ORI products as well as the mosaiced 50m DTM and 12.5m panchromatic ORI image mosaics are downloadable from the aforementioned link.

1.1 Instrument and Datasets

The High Resolution Stereo Camera (HRSC) onboard of the European Space Agency (ESA) Mars Express is a pushbroom camera with 9 different characteristics at 9 different angles: one nadir panchromatic channel (0°), two stereo channels (±18.9°), four-band colour channels (Red (15°), Green (2.4°), Blue (- 2.4°), and Near Infra-Red(-15°)) and two photometry channels (±12.8°). HRSC started its operation in 2003 (MY26), HRSC is still working until the present-day (2019) (MY35).

Overlapping HRSC strips over the Martian South Pole were selected based on spatial and temporal coverage to produce single DTM strips and the corresponding ORIs. The DTM strips and ORIs were then merged into separate mosaiced product.

1.2 Abbreviations and Acronyms

DLR	German Aerospace Centre
DTM	Digital Terrain Model
DUG	Data User Guide
ESA	European Space Agency
EU FP-7	European Union's Seventh Framework Programme
GIS	Geographic Information System
HRSC	High-Resolution Stereo Camera
JPL	Jet Propulsion Laboratory
MOLA	Mars Orbiter Laser Altimeter
MY	Martian Year

NASA	National Aeronautics and Space Administration (United States)
ORI	OrthoRectified Images
PSA	Planetary Science Archive
SPRC	South Polar Residual Cap
UCL	University College London
WebGIS	Web-based Geographic Information System
VICAR	Video Image Communication and Retrieval

1.3 Reference and Applicable Documents

Kim, J.R. and Muller, J.P., 2009. Multi-Resolution Topographic Data Extraction from Martian Stereo Imagery. Planetary and Space Science, 57(14-15), pp.2095-2112.

Neukum, G. and Jaumann, R., 2004, August. HRSC: The High-Resolution Stereo Camera of Mars Express. In Mars Express: The Scientific Payload (Vol. 1240, pp. 17-35).

Putri, A.R.D., Sidiropoulos, P., Muller, J.P., Walter, S.H. and Michael, G.G., 2019. A New South polar Digital Terrain Model of Mars from the High-Resolution Stereo Camera (HRSC) onboard the ESA Mars Express. Planetary and Space Science. https://doi.org/10.1016/j.pss.2019.02.010

Shin, D. and Muller, J.P., 2012. Progressively Weighted Affine Adaptive Correlation Matching for Quasi-Dense 3D Reconstruction. Pattern Recognition, 45(10), pp.3795-3809.

Smith, D.E., Sjogren, W.L., Tyler, G.L., Balmino, G., Lemoine, F.G., and Konopliv,A.S., 1999, The gravity field of Mars—Results from Mars Global Surveyor:Science, v. 286, p. 94–96.

Walter, S. H. G.; Muller, J. P.; Sidiropoulos, P.; Tao, Y.; Gwinner, K.; Putri, A. R. D.; Kim, J. R.; Steikert, R.; vanGasselt, S.; Michael, G. G.; Watson, G.; Schreiner, B. P. The Web-based Interactive Mars Analysis and Research System for the iMars project. *Earth and Space Science* **2018**, 32pp.

2. SCIENTIFIC OBJECTIVES

Over the past 5 decades, many areas on Mars have been imaged with serendipitous stereo, mainly to improve the potential for scientific studies. The rapid progress in planetary surface reconnaissance instrumentation, especially in relation to 3D imaging of the surface, has allowed change detection analysis. For example, by overlaying different high-resolution imagery from distinct time epochs (starting back in the mid 1970's) one can examine dynamic features, such as the recent discovery on Mars of mass (e.g. boulder) movement, tracking inter-year changes of seasonal phenomena (e.g. Swiss Cheese Terrain) and looking for fresh craters from meteoritic impacts.

The south pole of Mars is an area where a lot of these changes occur. It is commonly accepted in the planetary science community that research greatly benefits from the availability of high-resolution 3D models of Mars in general and the south pole of Mars, in particular. Within the EU FP-7 iMars (http://www.i-mars.eu) project, the consortium focused on developing tools and producing value-added datasets to maximize the exploitation of the available planetary datasets of the Martian surface. This includes the generation of high quality co-registered DTMs and corresponding terrain-corrected ORIs, using data from different NASA and ESA instruments.

2.1 Acknowledgements

Users are requested to acknowledge the dataset by mentioning it in any relevant figure captions and within acknowledgement within their publications to cite both the DOI of the dataset and the paper describing the processing system, assessment, and mosaic generation:

Putri, A.R.D., Sidiropoulos, P., Muller, J.P., Walter, S.H. and Michael, G.G., 2019. HRSC South Polar Digital Terrain Model of Mars.

Accessible at https://www.cosmos.esa.int/web/psa/UCL-MSSL_iMars_HRSC_v1.0

https://doi.org/10.5270/esa-0j79yk8

Putri, A.R.D., Sidiropoulos, P., Muller, J.P., Walter, S.H. and Michael, G.G., 2019. A new south polar Digital Terrain Model of mars from the High-Resolution Stereo Camera (HRSC) onboard the ESA Mars Express. Planetary and Space Science. https://doi.org/10.1016/j.pss.2019.02.010

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3. DATA PRODUCT GENERATION

The dataset is generated using a modified stereo processing pipeline (Kim and Muller, 2019) based on the open-source NASA VICAR (Video Image Communication and Retrieval) software, modified with proprietary software developed at DLR for use with HRSC images (DLR-VICAR) (Scholten et al., 2005). The modification utilizes the Gotcha (Gruen-Otto-Chau) algorithm (Kim and Muller, 2009; Shin and Muller, 2012).). This pipeline is illustrated in Figure 1. The pipeline, assessment, and mosaic generation of the dataset are discussed in more detail in Putri, et al., 2019)

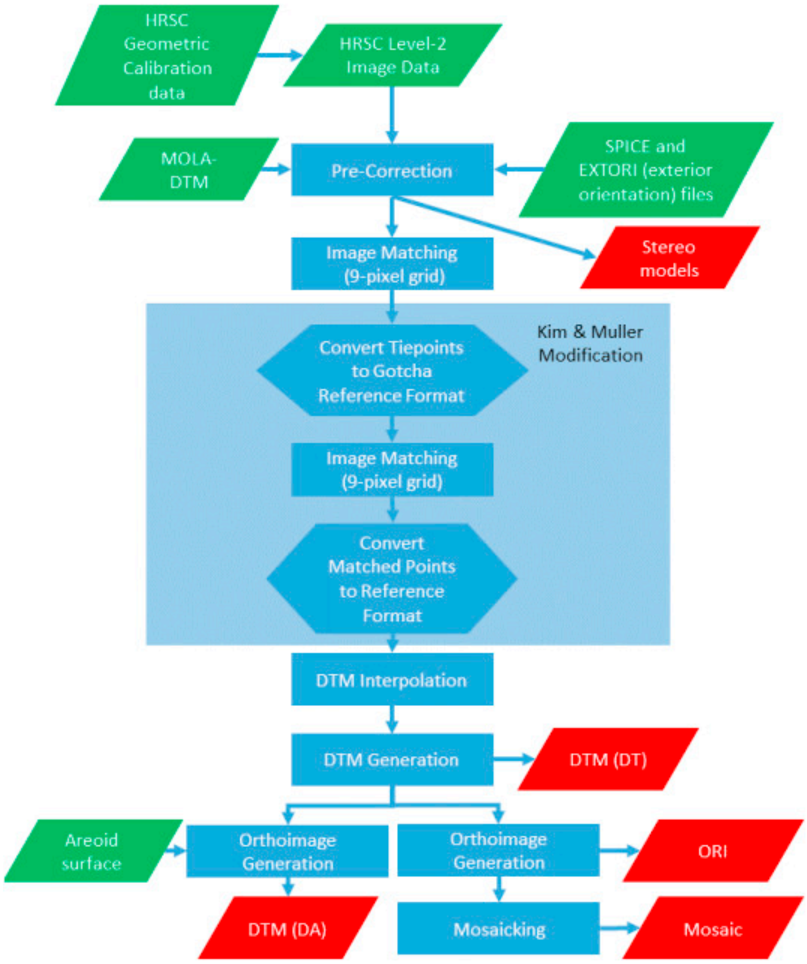


Figure 1 Schematic of modified DTM production algorithm based on DLR-VICAR (Kim and Muller, 2009; Putri, et al., 2019)

4. ARCHIVE FORMAT AND CONTENT

4.1 Product Type

A complete set of iMars 3D products for each strip of stereo HRSC images contains the following types of products:

- DTM (MOLA sphere and Mars areoid)
- ORI
- Metadata file

Global mosaics were produced with all 33 DTMs and corresponding ORIs using gdal_merge (https://www.gdal.org/gdal_merge.html). These mosaiced products are also included in this dataset and contain the same type of products.

4.2 Naming Convention

Each set of the iMars 3D product is contained in a directory with a similar naming convention to HRSC level 4. The naming convention for the different types of products listed in (1) is as follow:

- DTM (MOLA sphere) : PRODUCT_ID_dt4_ucl.tif
- DTM (areoid) : PRODUCT_ID_da4_ucl.tif
- ORI : PRODUCT_ID_nd4_ucl.tif
- DTM (MOLA sphere) mosaic : sprc_mosaic_dtm.tif
- DTM (areoid) mosaic : sprc_mosaic_ori.tif
- Metadata file : PRODUCT_ID_*4_ucl.pvl
- Shapefile : PRODUCT_ID.shp
PRODUCT_ID.shx
PRODUCT_ID.dbf
PRODUCT_ID.prj
PRODUCT_ID.qpj

4.3 Format Type

- DTM: int16; 1 channel; Geotiff image.
- ORI: byte; 1 channel; Geotiff image.
- Metadata file: ASCII file in PVL format
- Shapefile: GIS-ready (ArcGIS, QGIS, ENVI, etc.) shapefile format

4.4 DTM/ORI Specification

- Projection: Polar Stereographic
- Mars radius reference: MOLA sphere (dt), MOLA aeroid (da)
- DTM resolution: 50m/ pixel
- ORI resolution: 12.5-50m/pixel
- NoData value: -32768 (DTM), 0 (ORI)

4.5 Product Example and Usage

The DTM and ORI file in GeoTiff format can be opened in GIS/image processing software such as ArcGIS, QGIS, and ENVI. Projection and mapping information is embedded in the header of the Geotiff file as well as listed in the PVL metadata file as follows:

Example of gdalinfo output of h2163_0000_nd4_ucl.tif

```
Driver: GTiff/GeoTIFF
Files: h2163_0000_nd4_ucl.tif
Size is 12344, 22573
Coordinate System is:
PROJCS["STEREOGRAPHIC MARS",
    GEOGCS["GCS_MARS",
        DATUM["D_MARS",
            SPHEROID["MARS",3396000,0]],
        PRIMEM["Reference_Meridian",0],
        UNIT["degree",0.0174532925199433]],
    PROJECTION["Stereographic"],
    PARAMETER["latitude_of_origin",-90],
    PARAMETER["central_meridian",0],
    PARAMETER["scale_factor",1],
    PARAMETER["false_easting",0],
    PARAMETER["false_northing",0],
    UNIT["metre",1,
        AUTHORITY["EPSG","9001"]]]
Origin = (-429112.500000000000000,711112.500000000000000)
Pixel Size = (25.000000000000000,-25.000000000000000)
Metadata:
PRODUCER_DETAILS:https://www.cosmos.esa.int/web/psa/UCL-
MSSL_iMars_HRSC_v1.0
       PRODUCER.INSTITUTION_NAME = "University College London"
      PRODUCER.ORGANISATION = "UCL/MSSL"
      PRODUCER.PROCESSING_RESOURCE = "Imaging Group Blades"
      PRODUCER.CONTACT_PERSON = "Alfiah Rizky Diana Putri and Jan-
Peter Muller"
      PRODUCER_CONTACT_EMAIL = "alfiah.putri{at}ucl.ac.uk and
j.muller@ucl.ac.uk"
       PRODUCT.PROCESSING_DATE = "15 November 2016"

CONVERSION_DETAILS=http://www.lpi.usra.edu/meetings/lpsc2014/pdf/108
8.pdf
  FILE.EVENT_TYPE=MARS-REGIONAL-MAPPING-Gl-La
  HRCAL.RADIANCE_OFFSET=0.0
  HRCAL.RADIANCE_SCALING_FACTOR=0.0688398
```

```
  HRCAL.REFLECTANCE_SCALING_FACTOR=0.00162757
  HRCONVER.ERROR_FRAMES=0
  HRCONVER.MISSING_FRAMES=0
  HRCONVER.OVERFLOW_FRAMES=0
  HRFOOT.BEST_GROUND_SAMPLING_DISTANCE=0.0315
  HRORTHO.DTM_NAME=h2163_0000_dt4_ucl.vic
  HRORTHO.EXTORI_FILE_NAME=h2163_0000.nd2.ext_a
  HRORTHO.GEOMETRIC_CALIB_FILE_NAME=h2gnd_02.cal
  HRORTHO.SPICE_FILE_NAME=PCK00010.TPC
  M94_CAMERAS.MACROPIXEL_SIZE=1
  M94_INSTRUMENT.DETECTOR_ID=MEX_HRSC_NADIR
  M94_INSTRUMENT.MISSION_PHASE_NAME=MR_Phase_7
  M94_ORBIT.START_TIME=2005-09-20T09:13:23.625Z
  M94_ORBIT.STOP_TIME=2005-09-20T09:19:37.579Z
  PIXEL-SHIFT-BUG=CORRECTED
  PRODUCT_TYPE=IMAGE
  SPACECRAFT_NAME=MARS EXPRESS
Image Structure Metadata:
  INTERLEAVE=BAND
Corner Coordinates:
Upper Left  ( -429112.500,  711112.500) ( 31d 6'30.20"W, 76d
3'23.43"S)
Lower Left  ( -429112.500,  146787.500) ( 71d 6'56.17"W,
82d21'34.88"S)
Upper Right ( -120512.500,  711112.500) (  9d37' 6.78"W,
77d52'36.47"S)
Lower Right ( -120512.500,  146787.500) ( 39d23' 9.55"W,
86d47'47.69"S)
Center      ( -274812.500,  428950.000) ( 32d38'46.30"W,
81d25'16.22"S)
Band 1 Block=12344x1 Type=Byte, ColorInterp=Gray
  NoData Value=0
```

Example of PVL file h2163_0000_mt4_ucl.pvl

```
Object = ORI
  Object = ProductInfo
    Object = Producer
      SoftwareName = "NASA-DLR/VICAR"
      SoftwareVersion = 3.0
      OperatingSystem = "RHEL 6.7"
        ProducerInstitutionName = "University College London"
      ProcessingOrganisation = "UCL/MSSL"
      ProcessingResource = "Imaging Group Blades"
```

```
  ContactPerson = "Alfiah Rizky Diana Putri"
  ContactEmail = "alfiah.putri{at}ucl.ac.uk"
End_Object

Object = Image
  FileName = h2163_0000_nd4_ucl
  Format = GeoTiff
   Lines = 12344
   LineSample = 22573
  Band = 1
  BitDepth = Byte
  DTMResolution = 50
  ORIResolution = 25
  Unit = Metre
  NodataValue = 0
  Projection = "Polar Stereographic"
End_Object

 Object = DataProduct
  ID = h2163_0000
   InstrumentHostName = "Mars Express"
   InstrumentHostID = MEX
   TargetName = Mars
   InstrumentName = "High-Resolution Stereo Camera"
   InstrumentID = HRSC
   ProcessingLevel = 4
  ProductTypeName = "Orthorectified Image to HRSC DTMs"
  ProductTypeID = ucl
  DataSetName = "MSSL_iMars_HRSC_V1.0"
  ProcessingDate = "15 November 2016"
End_Object

 Object = MapProjection
  MapProjectionType = Equidistant
  ProjectionLatitudeType = Planetocentric
  AAxisRadius = 3396.0
  BAxisRadius = 3396.0
  CAxisRadius = 3396.0
   CoordinateSystemName = Planetocentric
   PositiveLongitudeDirection = East
   KeywordLatitudeType = Planetocentric
   CenterLatitude = -90
```

```
      CenterLongitude = 0
      MapScale = 25
      MaximumLatitude = 76.05651
      MinimumLatitude = 86.79658
      EasternmostLongitude = 350.38145
      WesternmostLongitude = 288.88440
  End_Object
End_Object




Object = Algorithm
  Group = DTMProcessing
    ExtoriFileName=h2163_0000.nd2.ext_a
    GeometricCalibFileName=h2gnd_02.cal
      MacropixelSize=1
      InstrumentDetectorID = "MEX_HRSC_NADIR"
      InstrumentMissionPhaseName = MR_Phase_7
    SpiceFilename=PCK00010.TPC
    SpatialResRatio = 1
  End_Group

   Group = ZKMatcher
      GaussFilter = 3
    MaximumDisparity = 5
      MinimumDisparity = -5
      DisparityRatio = 4
      ZKIteration = 5
      ZKCorrelation = 0.975
  End_Group

   Group = GruenMatcher
      GruenRadius = 9
      GruenCorrelation = 0.6
      GruenEigen = 600
  End_Group

  Group = GeoTiffConversion
    RadianceOffset = 0.0
    RadianceScalingFactor = 0.0688398
      ReflectanceScalingFactor = 0.00162757
    ErrorFrames = 0.0
```

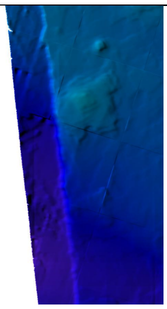
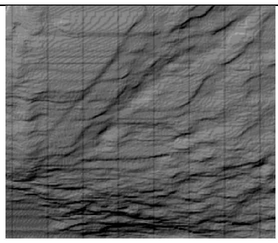
```
        MissingFrames = 0.0
        OverflowFrames = 0.0
      BestGroundSamplingDistance = 0.0315
    End_Group
  End_Object
End_Object
End
```

In both the GeoTIFF footer tag metadata and the PVL file, information on image, georeferencing, DTM production and conversion to GeoTIFF are available. The PVL metadata has added detail on matcher parameter and producer.

5. KNOWN ISSUES

There are known artefacts present in the HRSC DTMs released. Efforts have been made to try to reduce these artefacts, but looking at the individual colourised_by_height hillshaded relief maps to check whether the Region of Interest is affected is suggested before using the DTM for any quantitative purposes.

Table 1 Known Issues in Products

Issue	Explanation	Illustration
Edge jumps	Step artefact caused by higher differences over the edges of DTM strip from the matching procedure in Kim and Muller (2009). Efforts were undertaken to crop the edges of the DTM to exclude the artefacts, but a few pixels may still remain at the edge of the strips.	
Ripples in areoid (DA) products	Concentric lines caused by the rounding of MOLA values used in converting from DT (MOLA sphere) to DA (areoid) products. Efforts were undertaken to remove the artefacts, but some lines may still remain.	
Ripples in H4917_0009	Ripple artefacts occur in H4917_0009	

6. SOFTWARE

NASA-VICAR used as the base of this pipeline is released as open source (https://www-mipl.jpl.nasa.gov/vicar_open.html and https://github.com/nasa/VICAR)

It should be noted that it appears possible that you can create your own HRSC DTM + ORI products using the NASA Ames Stereo Pipeline (ASP) available through https://github.com/NeoGeographyToolkit

However, no testing or assessment has been made as to whether you can use this package without the improvements to the exterior orientation files used in this work. A version of ASP called CASP-GO has been developed for processing NASA-MRO CTX and HiRISE data as well as ESA Trace gas Orbiter CaSSIS data which will be released in the near future. We hope that this release will include explicit HRSC functionality.